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Buckling and Vibrational Analysis of Functionally Graded Materials on Beams

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ABSTRACT

With the rapid progress of advanced manufacturing technology,the functionally graded material (FGM) has emerged as a promising type of composites. By gradually varying the volume fraction of constitute materials, it not only combines the desired merits of several materials, such as the thermal resistance ability of ceramics and the strength of metals, but also eliminates the interlaminar stresses that usually exist in the traditional laminated composites.

In this thesis, the analytical investigation is done by using functionally graded materials for beams and plates for their strength, vibrations and buckling behaviour. The Functionally Graded Material with metal Aluminum alloy 6061 using Ceramic as interface zone is taken for analysis. FGM's are considered for volume fractions of K=2 and K=4.Theoretical calculations are done to compute the material properties for each layer up to 10 layers.

KEYWORDS: Functionally graded materials, Laminated composites, buckling behaviour.

INTRODUCTION

The reinforcement in composites used as structural materials in many aerospace and automobile applications is generally distributed uniformly. Functionally graded materials (FGMs) are being used as interfacial zone to improve the bonding strength of layered composites, to reduce the residual and thermal stresses in bonded dissimilar materials and as wear resistant layers in machine and engine components.

In materials science functionally graded material (FGM) may be characterized by the variation in composition and structure gradually over volume, resulting in corresponding changes in the properties of the material. The materials can be designed for specific function and applications. Various approaches based on the bulk (particulate processing), pre form processing, layer processing and melt processing are used to fabricate the functionally graded materials.

GOALS AND PURPOSES

- To provide the earthquake prone areas a hassle free constructions.
- Reduced operating costs due to lower cost of employing the beams made of FGM.
- To achieve greater results and a hassle free construction.

ADVANTAGES

- The first and foremost advantage is the weight of the material. FGMs are light in weight and therefore can easily be handled when compared to the other materials.
- They work absolutely fine in all the conditions since they are manufactured by the combination of merits and the elimination of demerits of materials used.

DISADVANTAGES

- One of the key disadvantages of FGMs is they are not economical.
- Another most usual failure is delamination, i.e., debonding of one layer from another.
- Structural health monitoring and nondestructive inspection of composites is much more difficult than for metals

LITERATURE SURVEY

Stress and Temperature Distribution Study in a Functionally Graded Brake Disk by P. Hosseini Tehrani, M.Talebi:

The simulation results show that the material properties of the disk brake exert an essential influence on the surface temperature, Von-Mises stress distribution and vertical displacement of the disk. It is shown that the temperature variation and vertical displacement in FGM disk is much lower than steel disk. Besides von-mises stress distribution in radial direction grows gradually and has not shown a maximum value in FGM disk. As a result the FGMs disk restrains the growth of thermal perturbation and delay the contact separation. Furthermore it is shown that localized contact is not as prevalent in FGM brake disk as steel disk and use of FGM brake disk may eliminate thermal cracking and wear in localized contact point or hot spots.

Modelling and Analysis of Functionally Graded Materials and Structures by Victor Birman and Larry W. Byrd:

This paper presents a review of the principal developments in functionally graded materials (FGMs) with an emphasis on the recent work published since 2000. Diverse areas relevant to various aspects of theory and applications of FGM are reflected in this paper. They include homogenization of particulate FGM, heat transfer issues, stress, stability and dynamic analyses, testing, manufacturing and design, applications, and fracture.

Free vibration of a functionally graded timoshenko beam by finite element method by Amal E. Alshorbagy, M.A. Eltaher, F.F. Mahmoud:

Functionally gradient materials (FGM) are one of the most widely used materials in various applications because of their adaptability to different situations by changing the material constituents as per the requirement. Most structural components used in the field of engineering can be classified as beams, plates, or shells for analysis purposes. In the present study the power law, sigmoid and exponential distribution is considered for the volume fraction distributions of the functionally graded plates. The work includes parametric studies performed by varying volume fraction distributions and boundary conditions. Also static analysis of functionally gradient material plate is carried out by sigmoid law and verified with the published results. The convergence study of the results is optimized by changing the mesh size and layer size. Power law and exponential law are applied for the same material and set of conditions.

Finite element vibration analysis of pre-stressed functionally graded plates by Venkataramana Naik, G Prasanthi, D Sudhakara and M Jayapal Reddy:

Studies free vibration of functionally graded beams Subjected to Axial Load that is simply supported at both ends lies on a continuous elastic foundation. The displacement field of beam is assumed based on Engesser-Timoshenko beam theory. The Young's modulus of beam is assumed to be graded continuously across the beam thickness. Applying the Hamilton's principle, the governing equation is established. Resulting equation is solved using the Euler's Equation. The effects of the constituent volume fractions and foundation coefficient on the vibration frequency are presented. To investigate the accuracy of the present analysis, a compression study is carried out with a known data.

A Review on Vibration Analysis of Functionally Graded Beams by C. Venkata Siva Murali, P. Suryanarayana Raju:

The present theory is based on a Higher-Order displacement model and the three-dimensional Hooke’s laws for plate material. The theory represents a more realistic quadratic variation of the transverse shearing and normal strains through the thickness of the plate. Nine-node Lagrangian elements have been used for the purpose of discretization using a refined Higher Order Shear deformation Theory (HOST12) that includes the effects of transverse shear deformations, transverse normal deformation and rotary inertia. A C0 isoperimetric finite element formulation is presented to calculate the required number of lowest natural frequencies of Functionally Graded Plates (Functionally graded plates) subjected to in-plane pre-stress. The material properties of the functionally graded plates are assumed to vary continuously from one surface to another, according to a simple power law distribution in terms of the constituent volume fractions. The formulation is applicable to thin as well as thick plates.

METHODOLOGY

The 3D model of beam and plate are made in PRO-E. After this the models are imported in to ANSYS workbench for buckling analysis, and vibrational analysis to observe the displacement, stress and deformation. We apply here the loads i.e.,pressure=0.0769N/mm^2 and respective conditions for the other materials. Now by using vibration theory of beams, we calculated force value according to respected values of all the materials considered. By comparing the results we choose the material preferable for our task.

MATERIAL PROPERTIES

	ALUMINIUM	STAINLESS STEEL
YOUNG'S MODULUS	68000MPa	230000MPa
POISSON'S RATIO	0.3	0.272
DENSITY	0.00000269kg/mm^3	0.0000077kg/mm^3
PRESSURE	0.0769N/mm^2	0.0769N/mm^2

FOR FGM:

1) For k=2; z=1

$E(Z)=(Et-Eb)(z/h+1/2)^{K}+Eb$

$=(380000-70000)(1/10+1/2)^{2}+70000$

$=(310000)\ (0.36)+70000$

$=181600$MPa

Above Same Procedure Is Repeated For k=2;and Z=2,3,4,5,-1,-2,-3,-4,-5.

2)For k=4; z=1

$E(Z)=(Et-Eb)(z/h+1/2)^{K}+Eb$

$=(380000-70000)(1/10+1/2)^{2}+70000$

$=310000\ (0.1296)+70000$

$=110176$MPa

Above Same Procedure Is Repeated For k=4;and Z=2,3,4,5,-1,-2,-3,-4,-5.

Density:

Material Properties:

Ceramic($\rho t=0.00000396$Kg/mm^3)

Aluminium($\rho b=0.0000027$ Kg/mm^3)

1)For k=2; z=1

$\rho(Z)=(\rho t-\rho b)(z/h+1/2)^{K}+\rho b$

$=(0.00000396-0.0000027)(1/10+1/2)^{2}+0.0000027$

$=1.26\times10^{-6}(0.36)+0.0000027$

$=3.1536\times10^{-6}$ Kg/mm^3

Above Same Procedure Is Repeated For k=2;and Z=2,3,4,5,-1,-2,-3,-4,-5.

2)For k=4; z=1

$\rho(Z)=(\rho t-\rho b)(z/h+1/2)^{K}+\rho b$

$=(0.00000396-0.0000027)(1/10+1/2)^{2}+0.0000027$

$=2.863\times10^{-6}$ Kg/mm^3

Above Same Procedure Is Repeated For k=4;and Z=2,3,4,5,-1,-2,-3,-4,-5.

Z	Youngs modulus E	Density
+5	380000	3.96×10^{-6}
+4	321100	3.7206×10^{-6}
+3	268400	3.5064×10^{-6}
+2	221900	3.3174×10^{-6}
+1	181600	3.1536×10^{-6}
-1	119600	2.9016×10^{-6}
-2	97900	2.8134×10^{-6}
-3	82400	2.7504×10^{-6}
-4	73100	2.7126×10^{-6}
-5	70000	2.7×10^{-6}

For K=4; Possions Ratio=0.3

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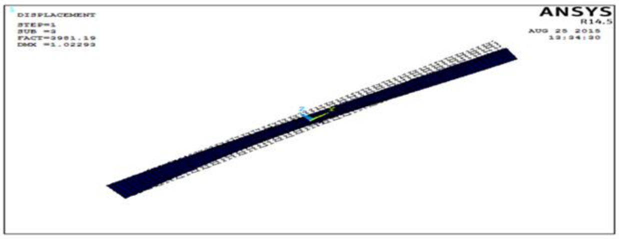
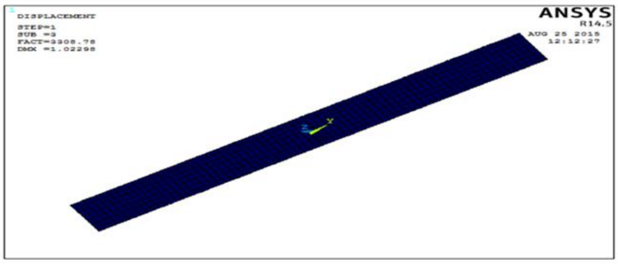
Z	Youngs modulus E	Density
+5	380000	3.96×10^{-6}
+4	273391	3.526×10^{-6}
+3	196976	3.216×10^{-6}
+2	144431	3.0025×10^{-6}
+1	110176	2.863×10^{-6}
-1	77936	2.732×10^{-6}
-2	72511	2.710×10^{-6}
-3	70496	2.7020×10^{-6}
-4	70031	2.70126×10^{-6}
-5	70000	2.7×10^{-6}

ANALYSIS

BUCKLING ANALYSIS



K=2

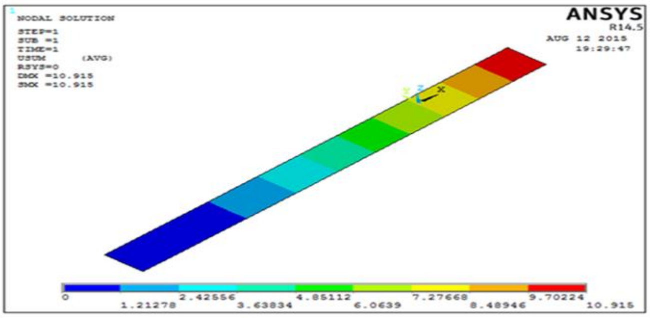


K=4

STRUCTURAL ANALYSIS

K=2

DISPLACEMENT:



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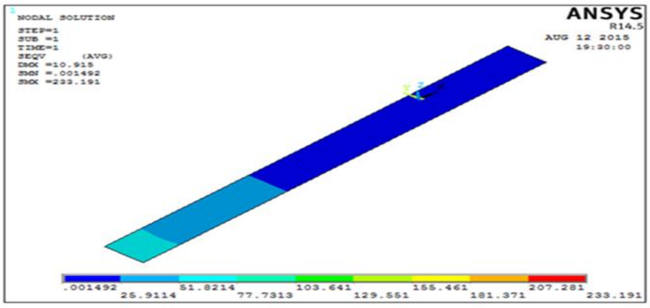

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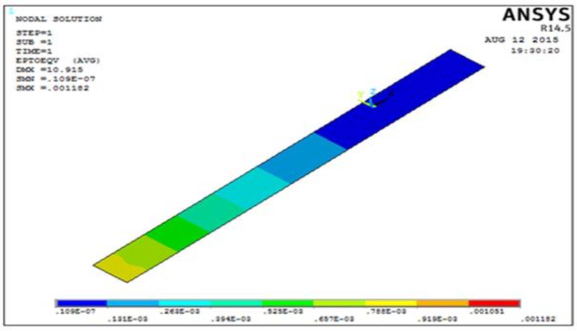
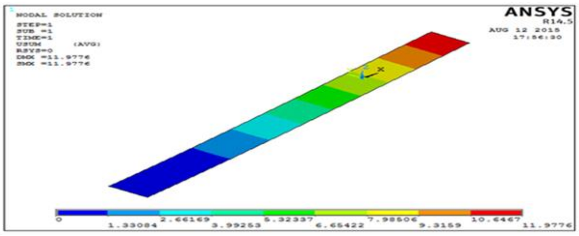


K=4

DISPLACEMENT



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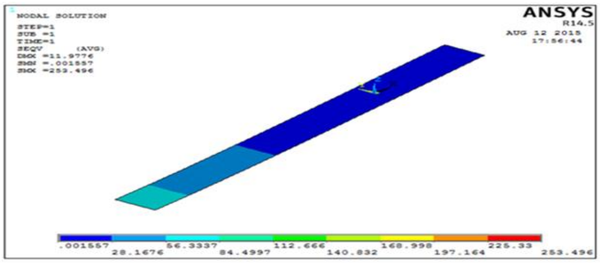

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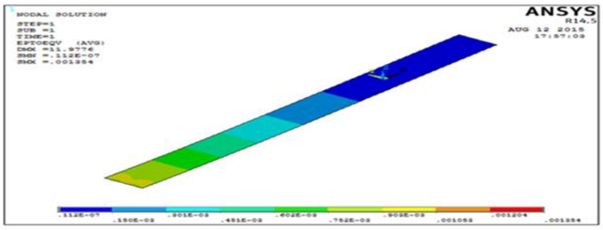
STRAIN



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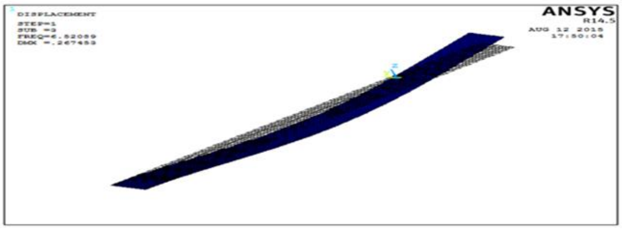
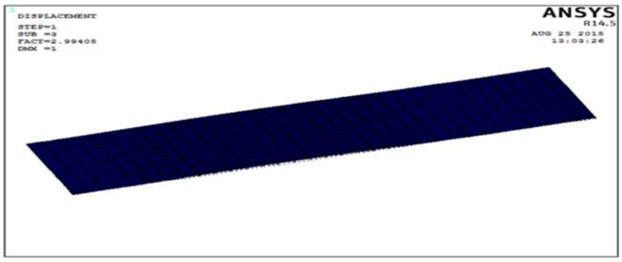


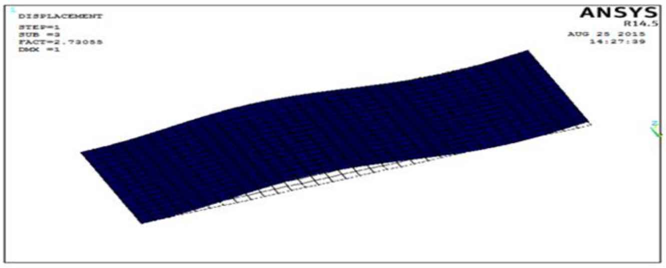
PLATES

BUCKLING ANALYSIS

K=2

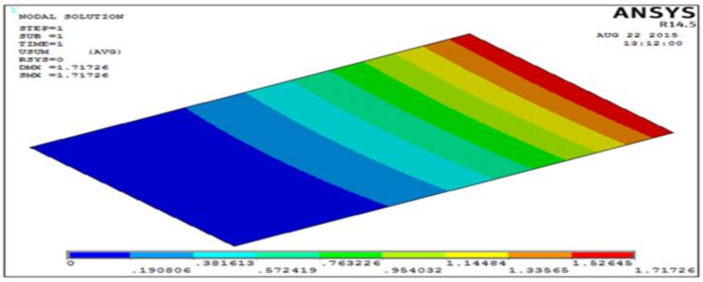


K=4



STRUCTURAL ANALYSIS

DISPLACEMENT



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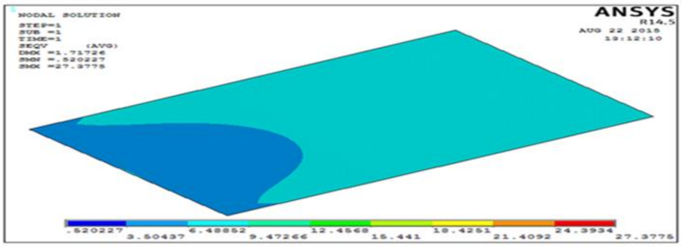

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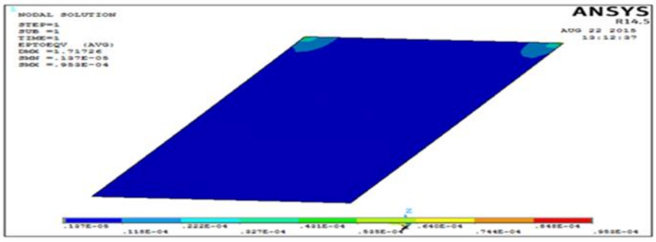
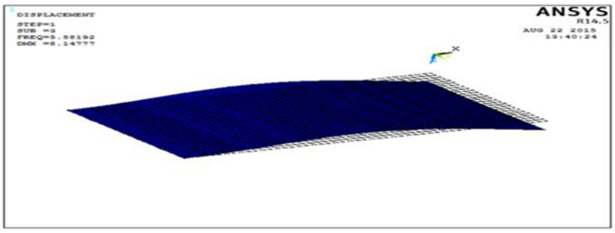
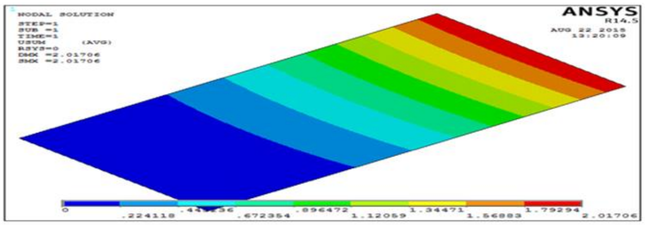


MODAL ANALYSIS



K=4

DISPLACEMENT



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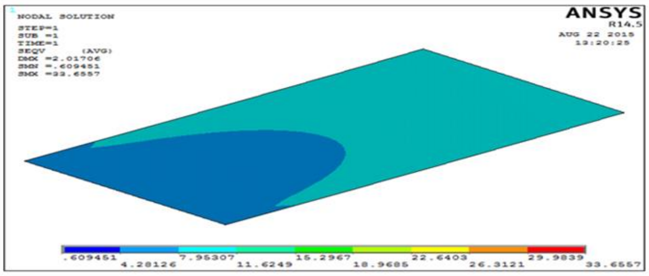

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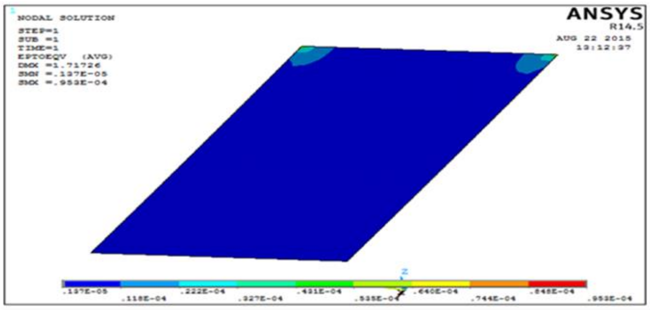
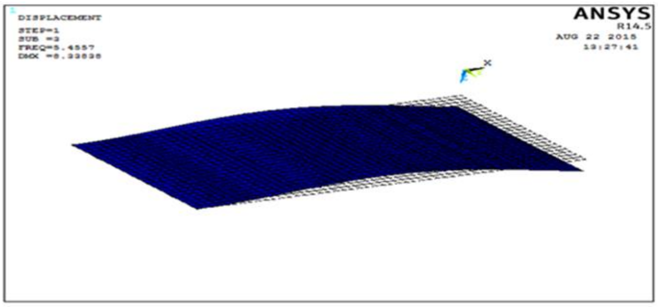


MODAL ANALYSIS



Likewise, have conducted analysis on materials Stainless Steel and Aluminium.

The results are given below in the form of tabular columns.

BUCKLING ANALYSIS FOR BEAMS

		Factor 1	Displacement (mm)	Factor 2	Displacement (mm)	Factor 3	Displacement (mm)
Aluminium		-295.469	1.01072	295.571	1.01064	435.002	1.0128
Stainless Steel		-1009.94	1.01055	1010.27	1.01047	1486.21	1.01272
FGM	K=2	-1220.11	1.01821	1195.4	1.01731	3981.19	1.02293
	K=4	-1051.08	1.01715	1026.82	1.01638	3308.78	1.02298

STRUCTURAL ANALYSIS

Materials		Displacement	Stress	Strain
Aluminium		20.1629	89.6255	0.001321
Steel		6.86123	89.3187	0.447E-03
Stainless Steel		5.97485	88.8089	0.387E-03
FGM	K=2	10.915	233.191	0.001182
	K=4	11.9776	253.496	0.001354

MODAL ANALYSIS

		Mode 1		Mode 2		Mode 3	
		Frequency	Displacement	Frequency	Displacement	Frequency	Displacement
Aluminium		1.7065	0.365884	5.33833	0.296491	12.8482	0.297065
Stainless Steel		0.933808	0.175596	1.85363	0.175217	5.79692	0.175544
FGM	K=2	1.07909	0.263559	2.4719	0.26308	6.69049	0.261712
	K=4	1.05409	0.269652	2.27217	0.269212	6.52089	0.267453

BUCKLING ANALYSIS FOR PLATES

		Factor 1	Displacement (mm)	Factor 2	Displacement (mm)	Factor 3	Displacement (mm)
Aluminium		-0.125372	1.00001	0.218452	0.999997	0.698632	0.999999
Stainless Steel		-0.421898	1.00001	0.73348	1	2.34264	0.999996
FGM	K=2	0.117893	1	1.06455	1	2.99405	1
	K=4	0.10753	1	0.970948	1	2.73055	1

STRUCTURAL ANALYSIS

Materials		Displacement	Stress	Strain
Aluminium		0.019548	16.5754	0.334E-03
Stainless Steel		0.005783	15.8095	0.699E-04
FGM	K=2	1.71726	27.3775	0.953E-04
	K=4	2.01706	33.6557	0.115E-04

MODAL ANALYSIS:

		Mode 1		Mode 2		Mode 3	
		Frequency	Displacement	Frequency	Displacement	Frequency	Displacement
Aluminium		0.658737	8.66728	2.82848	11.5568	4.10478	8.82603
Stainless Steel		0.712735	5.11844	3.09926	6.81583	4.44593	5.20366
FGM	K=2	0.895808	8.00287	3.8451	10.6716	5.58192	8.14777
	K=4	0.875574	8.19022	3.75694	10.9223	5.4557	8.33835

CONCLUSION:

The analytical investigation is done by using functionally graded materials for beams and plates for their strength, vibrations and buckling behaviour. Structural, Modal and buckling analysis is done on the two models by varying materials Aluminum, Steel, Stainless Steel and FGM.

By observing the buckling, structural and modal analysis results on beams, the following conclusions can be made:

- As per buckling results, the buckling is possible or predicted for plates under the given load conditions as the buckling load factors as per interpretation given for buckling and the displacements are less. Buckling load factor defines the load at which the applied load should be multiplied to buckle the beam. If FGM material is considered, the BLF's are more than other three materials, so FGM is better.
- As per the structural analysis results, the stresses and displacements are more when FGM is used than other materials but the stress values are less than the allowable stress values. So using FGM is safe under load conditions.
- As per modal analysis results, the frequencies are less for FGM so vibrations are less and displacements are also less.

FUTURE SCOPE:

The results discussed in this work are based on the simulations but the actual working conditions will be different, so practical work has to be done to analyze the advantages and disadvantages of using FGM for beams and plates. In the present work, thermal stresses are not considered, so investigating the thermal stresses in FGM's can enhance the use of these materials in Automobile components.

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2. Modeling and Analysis of Functionally Graded Materials and Structures by Victor Birman and Larry W. Byrd

3. Free vibration of a functionally graded timoshenko beam by finite element method by Amal E. Alshorbagy, M.A. Eltaher, F.F. Mahmoud

4. Finite element vibration analysis of pre-stressed functionally graded plates by Venkataramana Naik, G Prasanthi, D Sudhakara and M Jayapal Reddy

5. A Review on Vibration Analysis of Functionally Graded Beams by C. Venkata Siva Murali, P. Suryanarayana Raju

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